

EQUIPMENT FOR INVESTIGATION OF SECONDARY ELECTRON HIGH
FREQUENCY DISCHARGE AT SALYUT ORBITAL STATION — CONDUCT
OF EXPERIMENT AND ITS RESULTS

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16. Abstract Experiments relating to study of high-frequency secondary electron resonance discharge in the ionosphere are discussed. The basic characteristics of the equipment employed are given, and some of the results obtained are presented.			
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EQUIPMENT FOR INVESTIGATION OF SECONDARY ELECTRON HIGH
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OF EXPERIMENT AND ITS RESULTS¹

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1. Introduction

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V. I. Patsayev conducted a study of high frequency secondary electron resonance discharge at the Salyut orbital station in June 1971.

High frequency secondary electron resonance discharge is the term applied to the physical process in which there is a fluctuating space charge formed as a result of secondary electron emission from the surface of electrodes in the high frequency electric field between the electrodes [1, 2]. In the literature this process is also called "secondary electron resonance breakdown," and "multipactor discharge." The term "resonance discharge" is used in what follows for the sake of brevity.

Resonance discharge occurs in avalanche fashion on random entry of electrons into the electrode space. This effect was discovered by accident in the 1940s, in vacuum devices such as klystrons and charged particle accelerators. The basic laws of resonance discharge were determined for plane electrodes in a vacuum [1-4].

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The effect may be described in simplified form as follows. If a high frequency voltage is applied to plane electrodes in a vacuum (the mean free path of the electrodes is much greater than the electrode distance), electrons chancing to come between the electrodes may acquire energy sufficient to generate secondary emission from the electrode surface. When a specific relationship exists between the frequency and amplitude of a high frequency voltage and the electrode distance, the process assumes the nature of an avalanche. A considerable concentration of electrons is consequently created between the

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*Numbers in the margin indicate pagination in the foreign text.

the electrodes. Detailed study of the resonance discharge mechanism is a highly complex undertaking.

It may be noted that the high frequency voltage at which the discharge occurs (critical voltage) depends on the material and the surface condition of the electrodes and the duration of the discharge. The nature of the discharge is also influenced by the direct-current voltage supplied to the electrodes simultaneously with the high frequency voltage. It has been possible to suppress resonance discharge under vacuum conditions by increasing the direct-current voltage.

The results of the laboratory studies permit the assumption that resonance discharge can occur in systems with electrodes of complex configuration, and on the antennas of space vehicles in particular, the nature of the discharge being additionally influenced by the free electrons of the ambient medium. It is to be expected that in this instance the high frequency power is lost and the characteristics of the antenna systems are impaired. However, the impossibility of sufficiently complete simulation in vacuum chambers of the conditions of outer space and the effects created by the movement of the space vehicle has prevented the drawing of positive conclusions regarding the existence of such a /5 process under the conditions of actual flight into space.

The purpose of the studies described in this paper was experimental detection and study of the effect of resonance discharge under the conditions of flight by a space vehicle in the ionosphere, accompanied by measurement of the concentration of charged particles in the ionosphere. Measurement of the local concentration of charged particles in the ionosphere along the orbit of a space vehicle, which is necessary for fuller understanding of the results of resonance discharge research, is also of interest in itself.

If such studies were to be conducted in an unmanned space vehicle, the insufficient study devoted to the phenomenon would require the development of highly complex automatic equipment. The possibility of direct participation by the cosmonaut researcher in the experiment permitted the development and application of experimental equipment and of an experimental program designed for active participation by the experimenter in the measurements. The equipment made it possible to modify certain of the conditions under which the experiment

was conducted and at the same time to monitor several physical characteristics visually. The cosmonaut was able to modify the conditions under which the experiment was conducted in keeping with the results observed.

The first phase of measurement included chiefly detection of resonance discharge and determination of the conditions of its existence. At the Salyut orbital station the measurements were performed by cosmonaut V. I. Patsayev, who successfully conducted the first studies of resonance discharge in the ionosphere.

2. Measurement Procedures and Equipment

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2.1. Resonance Discharge Studies

Resonance discharge was investigated with electrodes of three types. The electrodes were similar in form to those of the antennas employed on space vehicles, and all the direct-current electrodes were insulated from the hull of the station. One of the electrodes, to which continuously adjustable high-frequency pulse voltages and direct step-controlled voltage was supplied, was in use at any given time.

It was necessary first of all to record the fact of occurrence of the discharge. Use was made for this purpose of a high-frequency discharge current meter based on increase in the conductance of the medium in the electrode space on occurrence of the discharge. The possibility of modifying the high-frequency power and direct-current voltage was necessary in order to determine the influence of the latter on the conditions of the occurrence and nature of the resonance discharge. A high-frequency probe — a receiver with two small antennas (frame and symmetrical vibrator) mounted on a rod which could be displaced in the vicinity of the electrodes — was employed to measure the distribution of the high-frequency field in the vicinity of the electrodes.

2.2. Measurements of Local Charged Particle Concentrations

Measurement of the concentration of positive ions n_i by the ion trap method [5] was performed in the experiments described. Inasmuch as the ionosphere is electrically neutral and negative ions are virtually absent at the altitude of flight of the Salyut station, measurements of concentration n_i automatically yield the values of electron concentration n_e .

Three spherical ion traps were mounted on the Salyut station. Two of them were stationary and were designed for the performance of measurements in the undisturbed medium, while the third was mounted on a movable rod holding the receiving antennas (two of the three traps could operate simultaneously). In the case of spherical traps the measurement results depend but little on the orientation of the trap relative to the Sun and the velocity vector of the oncoming flux of particles (until the trap enters the ion shade of the space vehicle). The inner electrode of the trap, the collector, had a negative constant potential. The potential of the outer electrode, the grid, was set by the experimenter. Whenever the grid potential underwent sawtooth variation, the volt-ampere characteristics of the current collector permitted determination of concentration n_i . /7

2.3. Certain Information on the Equipment

One of the three electrode systems on which the discharge was observed was connected at the discretion of the experimenter by means of a special switch to an adjustable attenuator (0-13 db) regulating the level of the high-frequency power from a pulse generator (pulse power $P = 300 \text{ W}$, carrier frequency around 180 MHz, pulse duration 3 μsec). The attenuator unit contained incident and reflected power pickups.

All the parameters measured were recorded on film by a small loop oscillograph. The film with the recordings was processed on Earth after the return of the space vehicle. In addition, the cosmonaut kept records in the log, which was also returned to Earth.

The schedule of the cosmonaut's work in connection with this particular experiment was set up as a part of the log. All the basic operations were listed and space was provided for recording of the results of measurements, effects observed, and comments.

The description of the sequence of operations was at first highly detailed. /8 However, it was learned during training of the cosmonauts that detailed instructions are not required for recurrent operations, and with the assistance of V. I. Patsayev the schedule was revised. In the final version only the purpose of a particular group of operations was indicated (for example, "recording"), and

standard operations such as this were decoded in detail at the end of the program. The tables set up for entering the results of observations in the log were also simplified.

Control of all the instruments of the array and indication of the measured parameters were concentrated in one instrument, a control unit by means of which the cosmonaut performed the experiment and observed its progress. An exterior view of the control unit is shown in Figure 1.

In particular the control unit contained relay circuits for control of the high-frequency power attenuator drive, movable rod drive, the high-frequency electrode switch control, and control of the various recording modes. The condition of the various control units was monitored by means of indicator lights, for which red and green light diodes were used.

Before coming to the oscillograph loops or pointer instruments all the measured currents and voltages were amplified by special amplifiers, which were also located in the control unit. The control unit also contained a measuring receiver with a stepped attenuator at the input. The probe current amplifiers permitted current measurement in the range from 10^{-10} to 10^{-5} a, which was divided into several component ranges. The values of all the parameters measured could be monitored on three pointer instruments which could be connected into various circuits at the discretion of the experimenter. The probe characteristics of the /9 ion traps could be observed on the screen of a cathode-ray tube. A photograph of the ion trap (10 cm in diameter) is presented in Figure 2.

The experimenter was able to select the optimum amplification conditions on the basis of the type of volt-ampere characteristic on the screen. The angle of inclination of the movable rod was recorded by means of a pointer instrument connected to a potentiometer pickup.

Despite the high concentration of control and monitoring elements on the panel (7 pointer instruments, a cathode-ray tube, 16 switches, 7 knobs, 9 cutouts, 6 regulators, 11 indicator lights, 2 film counters), use of the instrument occasioned the experimenter no particular difficulties. The entries made aboard the Salyut station by V. I. Patsayev contain no comments about difficulty in working with the instrument.

3. Measurement Results

V. I. Patsayev conducted a number of experiments over the period from 16-27 June 1971 with the equipment described above aboard the Salyut. The entries made by V. I. Patsayev in the log and oscillograph films returned to Earth permitted reconstruction of the course of the experiment. V. I. Patsayev held 8 measurement sessions ranging in length from 15 to 90 minutes. In the aggregate the loop oscillograph tape advance mechanism was switched on 202 times during the conduct of the experiments described; each recording reproduced from one to several dozen measurement cycles. V. I. Patsayev modified the measurement program established on Earth in keeping with the actual situation. Some of the /10 experiments were conducted during periods set aside for the cosmonaut's rest, this indicating his interest in the research conducted.

The map in Figure 3 illustrates the projections of the orbits of the Salyut station on which the resonance discharge studies were conducted. The measurement segments are indicated by twin fine lines; the symbol ● denotes a terminator and arrows indicate the direction of flight.

All these measurements were conducted while the station was rotating about the Y axis oriented toward the Sun (this axis being perpendicular to the longitudinal (major) axis of the station), at an angular velocity of around 3 deg/sec; the high-frequency electrodes and the ion traps were always shaded by the hull of the station from direct illumination by rays of the Sun, and consequently there was no photoemission from the electrodes of the traps.

One of the chief results of the experiments in initial discovery of the existence of resonance discharge on electrodes mounted on the surface of a space vehicle during its flight in the ionosphere. One of the oscillograms taken by V. I. Patsayev, on which the process of generation of resonance discharge is recorded, is reproduced in Figure 4. Also recorded on the oscillogram are the discharge current (1); the direct-current voltage on the electrode, which in this case equals +3.5 v (curve 2); the incident and reflected wave power values (curve 3, 4, respectively; a drop in the levels on the oscillogram corresponds to increase in values); and time marks at second intervals) (5). As the high-frequency voltage increases (with increase in the incident and reflected power), the discharge current also arises and increases, its level going beyond the

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limits of the recording field. (The values of the incident and reflected power are recorded on different scales, and the recordings are displaced 2 mm horizontally relative to each other.) The oscillogram in Figure 4 clearly shows the recurrent generation of a high-frequency secondary electron resonance discharge.

As the station rotates around the Y axis the orientation of the various sections of its surface changes constantly relative to the velocity vector (the direction of the oncoming flux of ionosphere plasma), it being possible for the high-frequency electrodes to enter the gas dynamic shade of the station. The effect of such shading was determined in a series of 20 measurements conducted at 1 minute intervals. Each measurement consisted of 3 cycles of variation of the high-frequency power, each cycle lasting 2 seconds. The power value was at the minimum during the intervals between measurements; there was no discharge during these intervals. The measurements were conducted along the daytime section of the orbit. It was found that the critical power and discharge current values vary as a function of change in the position of the station relative to the vector of the oncoming flux of plasma. The variations in the maximum discharge current values (dots) and critical power values (crosses) in time are illustrated in Figure 5 on a relative scale. Also entered in this graph, in solid lines, are sine-wave curves, the period of which corresponds to the period of rotation of the station. This rotation exerts a fairly pronounced effect on the discharge current.

We must point out that it was possible to record the resonance discharge in only one of the three electrode systems.

Measurements of the positive ions concentration were conducted during /12
several portions of the flight. The experimenter was to select the optimum measurement conditions on the basis of the form of the volt-ampere characteristic on the screen of the cathode-ray tube.

An analysis of the recordings revealed that the operation of the control unit probe amplifiers was not entirely normal (V. I. Patsayev was unable to see these irregularities in the operation of the instrument; they were manifested only on the recordings). Probe characteristics susceptible of decoding were nevertheless obtained along certain of the sections. Such recordings were

obtained, for example, on 16 June 1971 on an orbit segment approximately 3,000 km in length. The measurements were initiated in the area of a terminator, shortly before the station entered the shade. The flight altitude was 250 km, and the latitude ranged from 42° to 50° south latitude. The data obtained are shown in Table 1 (the distances entered with a minus sign correspond to the section of the orbit illuminated by the Sun).

A matter of interest in these measurements, along with the data obtained, is the fact itself that successful ionospheric measurements were performed by means of an instrument controlled by the cosmonaut. There are no entries in the log indicating difficulties in conducting the measurements. This verifies the efficiency of the device permitting measurement of the ion concentration under the complex conditions which may arise in study of resonance discharge, when it is necessary to make substantial changes in the range of the measured values of the concentration and potentials in the trap electrodes.

TABLE 1.

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Distance from terminator, km	Concentration n_i , 10^5 cm^{-3}
-500	1.6
- 25	1.8; 1.55
250	1.55; 1.55
500	1.45; 1.35; 1.35
750	1.35; 1.35
1,000	1.25; 1.2; 1.25; 1.2
1,250	1.25; 1.35
1,500	0.85; 1.0; 0.85
1,750	0.85
2,000	0.85
2,250	0.85; 0.75; 0.85
2,500	0.85; 0.85

Findings

In the present paper a description is given of experiments relating to investigation of high-frequency secondary electron resonance discharge in the

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ionosphere, and the basic characteristics of the equipment employed and some of the results obtained are presented.

The following are the basic findings:

(1) A high-frequency secondary electron resonance discharge on electrodes has been detected in the vicinity of the surface of an orbital station flying in the ionosphere.

(2) The high-frequency discharge current and the power at which the discharge occurs depend upon the orientation of the station relative to the vector of its velocity and change on transition from the nighttime to the daytime portion of the orbit.

Because of the length restrictions imposed on the paper, only part of the results obtained have been presented. In particular, no description has been given of the influence exerted on the discharge by the constant potential on the electrodes, the relationship of the nature of the discharge to its duration, or the influence of the discharge on electrode impedance.

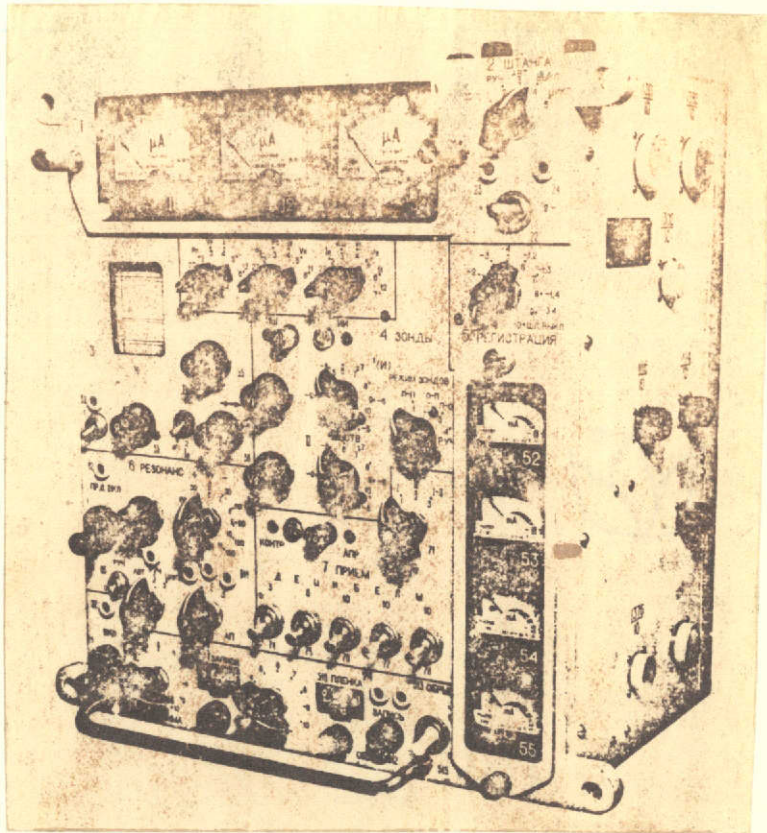


Figure 1. Exterior View of Control Unit.

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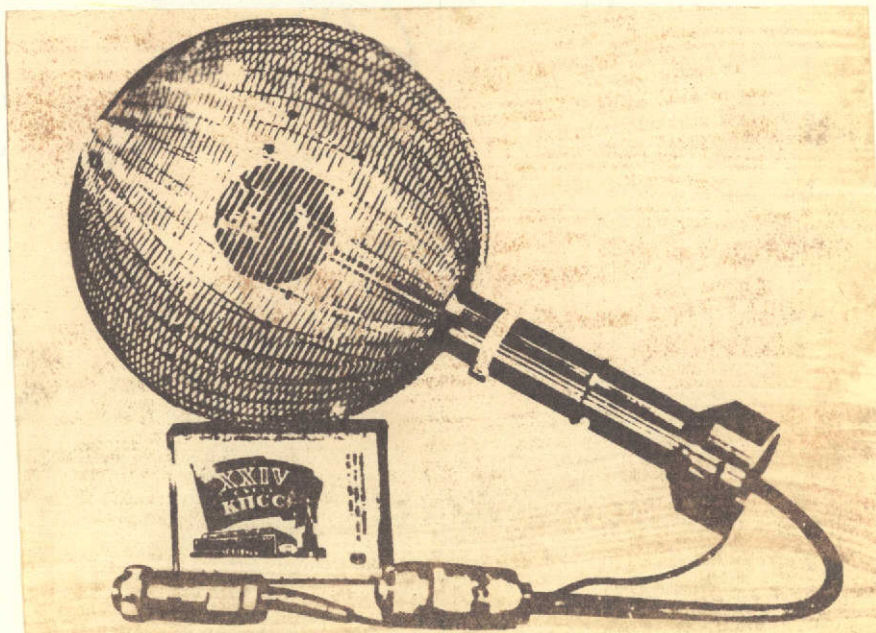


Figure 2. Spherical Ion Trap (10 cm in Diameter) Mounted on Salyut Station.

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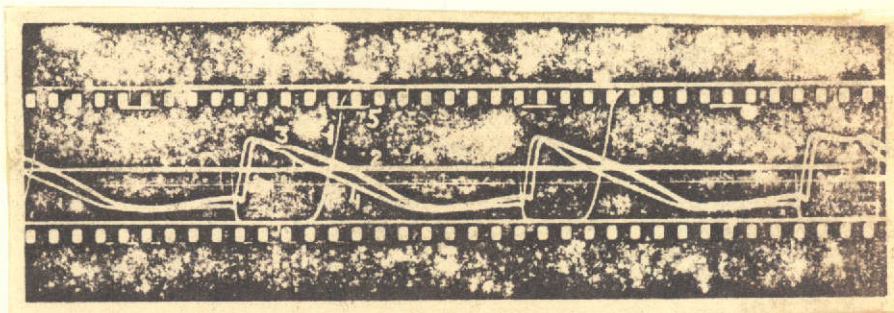


Figure 4. Oscillogram with Recording of Occurrence of Resonance Discharge, Obtained at 2330 hours Moscow Time on 25 June, 1971. 1, Discharge current; 2, direct-current voltage on electrode; 3 and 4, power of incident and reflected waves respectively.

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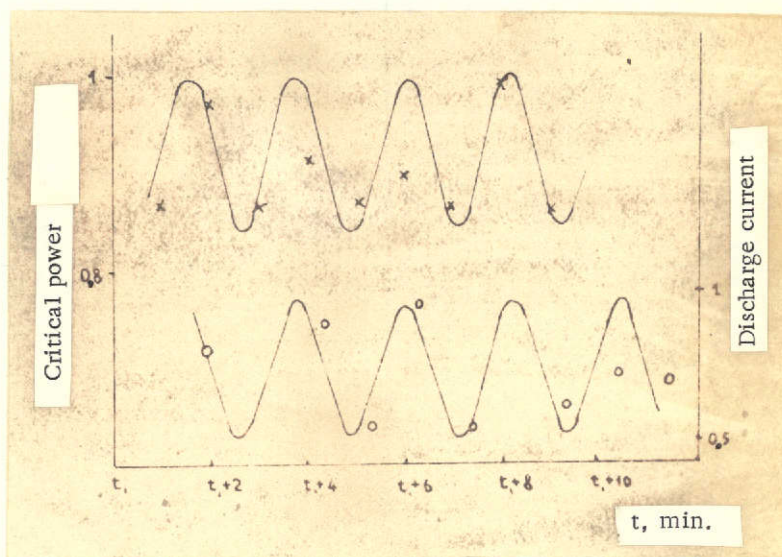


Figure 5. Maximum Values of Discharge Current (Dots) and Values of Critical Power (Crosses), Measured at Intervals of 1 Minute at 1135 Hours Moscow Time on 26 June 1971. Relative scale entered along the vertical. The period of the solid-line sine-wave curve corresponds to the period of rotation of the station.

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